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Classifying Soils for Acidic Deposition Aquatic Effects A Scheme for the Northeast USA

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16. ABSTRACT

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Classifying Soils for Acidic Deposition Aquatic Effects: A Scheme for the Northeast USA

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ABSTRACT

The Direct/Delayed Response Project (DDRP) is estimating the number of lakes and streams in three U.S. regions that might become acidic due to current or altered levels of acidic deposition, and the long-term time scales involved. Because of the influence of soils on aquatic chemistry, DDRP acquired data on soils that were mapped, sampled, and analyzed consistent methods across the regions. In the northeastern USA, about 600 soils (mainly phases of soil series) were identified during mapping of 145 watersheds. Because statistically adequate sampling of every soil was impractical, the soils were grouped into 38 sampling classes. Each of these classes was sampled across several (usually eight) watersheds. The properties of soils on specific watersheds (or portions of watersheds) can be estimated from the regional means and variances of the sampling classes and the percent occurrence of sampling classes on each watershed. This paper describes how the sampling classes for the northeastern USA were developed, the definitions of the classes, and the characteristics of soils within the classes. A preliminary statistical test indicates that the occurrence of sampling classes on watersheds is a significant predictor of Acid Neutralizing Capacity class of the corresponding lakes. Final evaluation of the utility of this scheme will come from the very extensive data analysis and modeling tasks of the DDRP.

THROUGH the Direct/Delayed Response Project (DDRP), the U.S. EPA is assessing the current and future effects of acidic deposition on surface waters (lakes, streams) in three regions of the eastern USA (Fig. 1). The DDRP is being conducted under the National Acid Precipitation Program (NAPAP), a multi-agency federal task force. Church and Turner (1986) give the details of the theoretical basis and approach of the DDRP.

One of the policy questions being addressed is: Within the regions of concern, how many surface water systems (lakes streams) might become acidic (on an average annual basis) due to current or altered levels of acidic deposition, and on what long term time scales (years to decades)?

In the Northeast Region, the DDRP randomly selected 145 watersheds with lakes that had been sampled as part of the Eastern Lake Survey (Linthurst et al., 1986; Landers et al., 1988). Three strata were used to select the DDRP watersheds. These were based on lake acid neutralizing capacity (ANC) as follows: Class 1, ANC <25 $\mu mol_c/L$; Class 2, 25–100 $\mu mol_c/L$; Class 3, 100–400 $\mu mol_c/L$. These watersheds are a probability sample of all lakes (the "target populations") in the region that meet the following criteria: lake area <4 ha; watershed area <3000 ha; acid neutralizing capacity (ANC) of lake <400 $\mu mol_c/L$; lake depth >1.5 m; not culturally disturbed.

Soils influence the response of surface waters to acidic deposition (Altshuller and Linthurst, 1984; National Academy of Sciences, 1984). The soil processes and corresponding soil characteristics considered within the DDRP are summarized in Table 1. These processes and characteristics are incorporated into three levels of analysis by DDRP. Level I analyses include statistical association of watershed characteristics with water chemistry. Level II analyses include estimates of the time required for key watershed characteristics to reach critical levels. Level III analyses use dynamic, integrated watershed models to estimate future responses to acidic deposition.

To perform the required analyses, the DDRP acquired data on soils that were mapped, sampled and analyzed using consistent methods in all regions. The mapping and sampling were done in cooperation with the USDA-SCS. An overview of soil survey activities within DDRP is given by Lee et al. (1989).

In the Northeast, about 600 soils (mostly phases of soil series; higher taxonomic units were used if no series had been established) were identified during mapping of 145 watersheds. Because of the large number of soils, it would have been impractical to sample each soil enough times to give statistically adequate estimates of the means and variances of the relevant soil properties.

As a practical alternative, the soils identified during mapping were combined into a tractable number of groups, or sampling classes, that were either known or expected to have similar chemical and physical characteristics with respect to their responses to acidic deposition. Each of these 38 sampling classes was sampled across several watersheds, so that the mean and variance of the characteristics of each sampling

Fig. 1. Regions of eastern USA included in the Direct/Delayed Response Project.

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class can be computed for the region. These regional means and variances can then be used in conjunction with the soil maps to build area or volume weighted estimates, with error estimates, of each watershed's characteristics. This could be done also for specific portions of watersheds, such as poorly drained soils near lakes. Note that, in this approach, a given soil sample does not represent the specific watershed from which it came. Instead, it contributes to a set of samples that, collectively, represent a specific sampling class on all DDRP watersheds within the region for which the sampling class is defined. Because the DDRP will estimate the uncertainties of its projections and conclusions, it is necessary to know the probable range of expression of a given characteristic for a sampling class within a region, and not just the value associated with the central concept of the class.

Basically, the soil sampling classes were used for statistical stratification for sampling, and for aggregation of data for analysis. This was necessary because DDRP needed to obtain soils information on a very extensive area while sampling a limited number of pedons. If, for example, DDRP had used a purely random scheme with each pedon representing 40 ha (larger than some DDRP watersheds), sampling would have been required on about 1700 pedons in the Northeast. By using soil mapping to determine the kinds of soils and their spatial distribution on the DDRP watersheds, and then using the accumulated soils knowledge and experience of the soil scientists who helped design the classes, DDRP objectives can be satisfied with approximately 300 sampled pedons in the Northeast.

The sampling classes represent a complex hypothesis regarding the relationships between soils, acidic deposition, and lakes. This paper describes how the sampling classes were developed, the definitions of the classes, and the general characteristics of soils within the classes. A preliminary statistical test on the relationship between ANC class and occurrence of sampling classes is also reported. Currently, the laboratory and field data on the sampling classes are being used in the extensive DDRP data analysis and modeling tasks. The results of these analyses, to be presented in numerous future papers, will provide the basis for the final evaluation of the utility of the scheme presented in this paper.

Table 1. Watershed processes, soil processes, and soil characteristics considered important within DDRP.

Watershed processes	Soil processes	Soil properties
Sulfur retention	Sorption Reduction Precipitation Biological: uptake, fixation, mineralization	Mineralogy: of soil, of parent material Oxides: of Al, of FE Organic matter Texture: surface area, percent clay Reducing vs. oxidizing chemistry
Base supply	Cation exchange Weathering Biological: uptake, fixation, mineralization	Cation exchange capacity Base saturation Mineralogy: of soil, of parent material
Hydrology	Flow: overland, groundwater, subsurface Soil-water contact	Drainage: contribution or proximity to surface water, reducing vs. oxidizing chemistry Texture: estimated hydraulic conductivity Macropores; coarse fragments, roots Soil depth: to bedrock, to impermeable layer

METHODS

Sampling classes were developed at a workshop by the field soil scientists responsible for soil mapping, in cooperation with the modelers and statisticians who would be using the data. Soils were split into different classes based on properties the soil scientists thought might be important for determining the responses of watersheds to acidic deposition. The goal was to provide adequate resolution for the modeling and analysis tasks of DDRP. Statistical separation of sampling classes was not a goal. The underlying rationale was that if the classes are in fact distinct, better resolution is attained by separating them. If, however, they turn out not to be distinct, then we have paid a small price in terms of precision; that is, the allocation of samples is not as efficient as it might have been. It is possible (and, in fact, expected) that soils were split into finer groups than were needed.

Workshop participants were requested to rank the five most important factors controlling the effects of acidic deposition on aquatic chemistry in the Northeast. Candidate factors are listed in Table 2. Parent material, both origin and mode of deposition, and factors related to drainage class or hydrologic group were identified as important factors to consider in segregating dissimilar soils. Soil taxonomic classes also were considered important in segregating dissimilar soils.

Participants were split into two groups, each of which produced provisional schemes for defining sampling classes. One group was asked to emphasize soil taxonomic classes while the other was asked to emphasize the major soil factors that might be important for aquatic chemistry. The resulting schemes for defining sampling classes were synthesized into the final scheme.

The characteristics of the major soils (i.e. contained in the name of at least one map unit), the percent composition of soils within each map unit, and the percent occurrence of map units in each watershed were entered into a dBase III software management system on an IBM PC-XT. This system was used during the workshop to sort soils into proposed sampling classes and to tally the number of watersheds and total area of occurrence of each proposed class

Table 2. Average rating of importance of candidate soil characteristics by workshop participants. Most important have rating 1, least important have rating 5.

Rank	Characteristic	Average rating
1	Origin of parent material (mineralogy)	1.0
2	Subgroup	1.5
2	Series	1.5
3	Slope	2.5
4	Great group	2.7
5	Hydrologic group	2.8
6	Mode of deposition of parent material	3.0
7	Drainage class	3.1
7	Depth to bedrock	3.1
8	Depth to impermeable material	3.4
9	Particle-size class	3.9
10	Vegetation class	4.8
11	Physiography, regional/local	5.0
12	Organic vs. mineral	5.0

Not rated in top five by any participant: slope shape, geomorphic position, permeability, acid/nonacid, and surface stoniness

within the region. The final synthesis was subject to the following practical constraints: restrict the number of classes to fewer than 50 so that 6 to 8 pedons could be sampled for each class (i.e., total number of pedons not more than 300); combine sampling classes that occurred in less than 5% of the watersheds (about 7 watersheds); combine sampling classes with total areas of less than 85 ha (about 0.1% of total area mapped in the region).

As a first approximation, the "major factors" group used parent material and drainage class to aggregate soils into 32 sampling classes. In comparison, the first approximation of the "soil taxonomy" group had about 70 classes. The major-factors approach was modified, after review, to incorporate soil taxonomy by including the subgroup designation. The addition of the taxonomic designations increased the number of sampling classes from 32 to about 60 classes.

Both approaches were reviewed and modified by assigning individual soils to other similar classes to satisfy the restrictions given above. The two resulting classification schemes were then compared. The workshop consensus was to adopt the taxonomic classification scheme for further modification and aggregation because many, but not all, of the major factors considered important for aquatic chemistry are integrated in taxonomic classification.

RESULTS AND DISCUSSION

Definition of Sampling Classes

The final revision and aggregation of similar soils resulted in the identification of 38 representative sampling classes (Fig. 2). The most important series (i.e., included in the names of map units) in each sampling class are summarized in Table 3. Some map units were named for soils for which series were not established; for these, the finest level of taxonomic classification identified by the field soil scientists is listed in Table 3. The area and number of watersheds in which the final sampling classes occur as important soils are summarized by ANC class in Table 4.

Spodosols were separated because of the accumulation of aluminum oxides, iron oxides and organic matter in spodic horizons. These would affect cation exchange capacity (CEC) and sulfate adsorption, properties important for ANC (Altshuller and Linthurst, 1984; National Academy of Sciences, 1984). Aluminum is also of interest as the toxin primarily responsible for the adverse effects of acidification on aquatic organisms (Altshuller and Linthurst, 1984).

The primary split on mode of deposition of parent material was glacial till vs. glaciofluvial, implying differences in the degree of sorting of parent material. This distinction was made because particle-size distribution correlates with many properties of interest, such as cation exchange capacity (CEC) and hydraulic conductivity.

The wettest soils (e.g., Aquods, Aquepts, aquic subgroups, nonfolist Histosols) were separated because of their likely role as source areas for surface waters. They are also likely to differ from other soils in having a reducing rather than oxidizing chemical environment. This is especially important for sulfate retention. (Histosols would obviously be different from the other soils in most properties of interest.) Because approximately equal numbers of pedons were sampled for all sampling classes, separating the wettest soils resulted in greater allocation of sampling efforts to those soils in closest proximity to the surface waters.

The use of drainage classes to define sampling classes was considered by the workshop. The consensus was to use aquic vs. nonaquic instead because these taxonomic terms are better defined and used

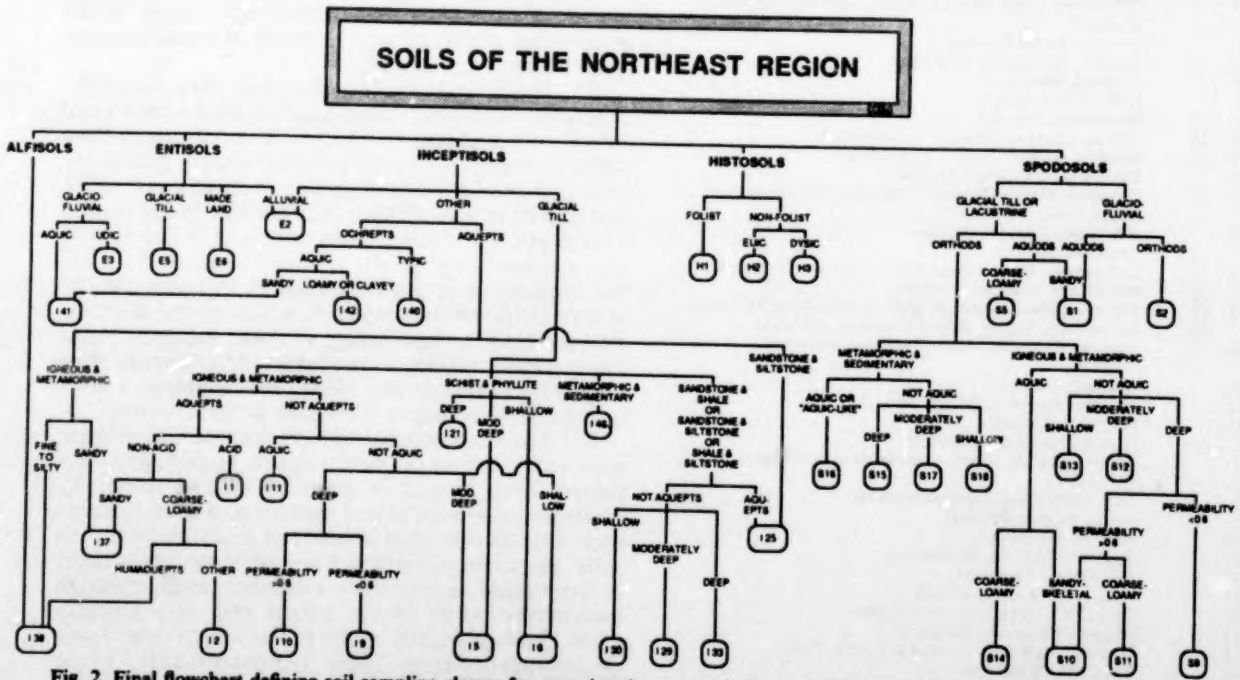

Fig. 2. Final flowchart defining soil sampling classes for assessing the potential effects of acidic deposition in the northeastern USA.

more consistently by soil scientists than are the somewhat subjective drainage classes. The aquic vs. nonaquic split was made at the suborder (e.g., Aquepts vs. Ochrepts) and subgroup (e.g., Typic Dystrochrepts vs. Aquic Dystrochrepts) levels.

One example of how classes were split is the group S15, S17, and S18. These are all nonaquic Orthods formed on similar parent materials, and are likely to have very similar chemical and physical properties, especially in the upper horizons. The distinction among them is soil depth: deep, moderately deep, and shallow, respectively. This split reflects the ILWAS hypothesis (Gherini et al., 1985) that soil depth may be the most relevant soil property in the Northeast. Aquic soils were not split by depth because the consensus was that these soils were hydrologically similar.

Another example is I37 and I2. Both classes contain wet, nonacidic Inceptisols formed from similar parent materials. They differ in family particle-size: sandy vs. coarse-loamy. In other words, soils in I37 contain greater than 50% sand, and those in I2 less than 50% sand in the particle-size control section. If these soils range far from the 50% breakpoint, then these classes are likely to differ in properties of interest to DDRP. If, however, they cluster near the 50% breakpoint, the classes might not be separable; more importantly, there would be no reason to separate them. The latter case is an example of the conservative approach to defining classes.

Figure 2 reflects the practical constraints on defining sampling classes, including those listed above. For example, all the soils in class S1 are from "igneous and metamorphic" parent material; thus, no split on mineralogy of parent material was needed. Similarly, all soils in class I33 have "coarse-loamy" particle size, and most are Fragiochrepts. The only soil in I33 that is not "slowly permeable" occurs only as an aquic inclusion on the DDRP watersheds; defining a sampling class for this soil would have been impractical and unnecessary. The two soils in class I5 have different parent materials; they were grouped to avoid having two classes each with a single soil. Thus, Fig. 2 represents a compromise between what was theoretically desirable and what was operationally practical. It should be noted that Fig. 2 is meant to apply only to soils on the watersheds of lakes in the DDRP target population.

The soils listed in Table 3 are not restrictive. The intent is for every soil in the northeast watersheds represented by DDRP to fit into one and only one sampling class. It is not necessary for a soil to fit specific series criteria to fit into a sampling class. Sampling classes are defined by the final flowchart (Fig. 2), which can be used to assign soils to sampling classes.

Table 3. Summary of major soils in final sampling classes.

Class	Soils
E2	Aquents, Basher, Charles, Fluvaquents, Medomak, Rumney, Udifluvents
E3	Carver, Hinckley, Plymouth, Udipsamments, Windsor
E5	Schoodic, Lithic Udorthents
E6	Udorthents
H1	Mahoosuc, Ricker
H2	Adrian, Carbondale, Carlisle, Cathro, Lupton, Medisaprists, Palms, Rifle
H3	Beseman, Borosaprists, Chocorua, Dawson, Freetown, Greenwood, Loxley, Ossipee, Sebago, Swansea, Vassalboro, Waskish
I1	Leicester, Lyme, Pillsbury
I2	Brayton, Haplaquepts, Ridgebury
I5	Chatfield, Macomber
I6	Hollis, Insula, Taconic
I9	Broadbrook, Montauk, Paxton
I10	Canton, Charlton, Gloucester, Narragansett
I11	Rainbow, Scituate, Sutton, Woodbridge
I21	Dummerston, Fullam, Lanesboro
I25	Chippewa, Malone, Morris, Neversink, Norwich, Rexford, Scriba, Tuller, Volusia
I29	Lordstown, Manlius, Oquaga
I30	Arnot, Nassau
I33	Lackawanna, Mardin, Swartswood, Wellsboro, Wurtsboro
I37	Moosilauke, Scarboro, Searsport
I38	Biddeford, Humaquepts, Muskellunge, Peacham, Raynham, Roundabout, Tughill, Swanville, Scantic, Whitman
I40	Agawam, Braceville, Haven, Merrimac, Riverhead, Wyoming
I41	Deerfield, Sudbury
I42	Belgrade, Boothbay, Buxton, Scio, Tisbury
I46	Burnham, Monarda
S1	Naskeag, Naumburg, Pipestone
S2	Adams, Allagash, Colton, Croghan, Duane, Masardis, Sheepscot
S5	Aeric Haplaquods, Typic Haplaquods
S9	Becket, Marlow, Potsdam
S10	Hermon, Waumbek
S11	Berkshire, Danforth, Monadnock
S12	Rawsonville, Tunbridge
S13	Hogback, Lyman, Saddleback
S14	Crary, Peru, Skerry, Sunapee, Worden
S15	Bangor, Chesuncook, Enchanted
S16	Dixmont, Howland, Nicholville, Surplus, Telos
S17	Elliotsville, Winnecook
S18	Monson, Thorndike

Characteristics of Soils Within Sampling Classes

Summarized below are the characteristics of soils within each sampling class. Subgroups represented in each class are listed in parentheses. Some soils were identified by the field soil scientists only to suborder or great group; for these the appropriate taxonomic classification is listed in parentheses. Gaps in the numbering of classes are the result of consolidations from preliminary schemes.

E2. This class consists of deep and very deep mineral soils formed in alluvial deposits from various and mostly mixed parent materials on flood plains and low terraces of streams where flooding usually occurs annually. The alluvial sediments commonly are stratified and have an irregular decrease in organic carbon with depth. Particle-size class ranges from fine-silty to coarse-loamy over sandy or sandy skeletal. Soils are well-drained to very poorly drained and permeability is slow to moderately rapid. Reaction ranges from extremely acid to moderately alkaline: Aquents, Aeric Fluvaquents, Mollic Fluvaquents, Udifluvents, Fluvaquentic Humaquepts, Histic Humaquepts, Fluvaquentic Dystrochrepts, Fluventic Dystrochrepts.

E3. This class consists of very deep, sandy, mineral soils with little or no development of pedogenic horizons. They formed in glaciofluvial and eolian deposits derived from mixed igneous and metamorphic rock. Particle-size class is sandy or sandy-skeletal. The soils are excessively drained and permeability is rapid or very rapid. Reaction is extremely acidic through moderately acidic in the solum and very strongly acidic through slightly acidic in the substratum: Typic Quartzipsamments, Typic Udipsamments, Typic Udorthents.

E5. This class consists of very shallow mineral soils with hard bedrock within 25 cm of the surface. These soils have little or no pedogenic development and formed in glacial till derived from mixed igneous and metamorphic, schist and phyllite or interbedded shale and siltstone lithology. Particle-size class is loamy or loamy-skeletal. The soils are well-drained to excessively drained and permeability is moderate to rapid: Lithic Udorthents, Lithic Cryorthents.

E6. The soils of this class mainly occur as areas disturbed by human activity including strip mines, pits and quarries, and landfills. These are deep mineral soils with recent disturbance that has destroyed or homogenized pedogenic development. The soil parent material is mainly glacial till from various parent rocks. Particle-size class is variable or loamy-skeletal. The soils are well-drained or somewhat excessively drained and permeability is moderately slow to moderately rapid: Udorthents.

H1. The soils of this class consist of freely drained organic materials derived from leaf litter, twigs and branches. These soils have organic materials resting on or partly filling interstices between rock fragments, or directly overlying bedrock that is less than 1 m from the surface. They are cool, have a frigid or cryic temperature regime, are somewhat excessively drained, and have moderately rapid to very rapid permeability. Thin (<10 cm) mineral layers may occur, but the combined thickness of the organic material is more than twice that of the mineral material: Typic Borofolists, Lithic Borofolists.

H2. This class consists of deep soils in organic material or organic material (40–130-cm thick) overlying mineral layers. The soil reaction is euic [the pH of undried samples is 4.5 or more (measured in 0.01 *M* $CaCl_2$) in at least some part of the organic materials in the control section] instead of dysic. Particle-size class of the mineral layers is loamy, sandy, or sandy-skeletal. These soils are very poorly drained or poorly drained and permeability is moderately slow to moderately rapid. Groundwater is at or near the surface nearly all the time. Mineral layers and layers of less decomposed organic material in some of the soils of this class tend to interfere with water movement: Typic Medifibrists, Typic Borohemists, Typic Borosaprists, Hemic Borosaprists, Terric Borosaprists, Typic Medisaprists, Terric Medisaprists.

H3. This class consists of deep soils in organic material, or organic material (40–130-cm thick) overlying mineral layers. The soil reaction is dysic [the pH of undried samples is less than 4.5 (measured in 0.01 *M* $CaCl_2$) in all parts of the organic materials in the control section] instead of euic. Particle-size of the mineral layers is loamy, sandy or sandy-skeletal. These soils are very poorly drained and permeability is moderately slow to rapid. Groundwater is at or near the

Table 4. Summary of occurrence of sampling classes as major soils on watersheds, within each acid neutralizing capacity (ANC) class.

Sampling class	Total area, ha	Number of watersheds	ANC Class 1		ANC Class 2		ANC Class 3	
			Area, ha	Number of watersheds	Area, ha	Number of watersheds	Area, ha	Number of watersheds
Rock	78	7						
E2	381	26	126	10	46	7	209	9
E3	1436	20	550	10	584	5	301	5
E5	505	15	253	6	252	6	0	0
E6	136	7	6	2	0	0	130	4
H1	646	22	150	9	232	7	243	6
H2	518	18	89	7	313	5	116	6
H3	2950	83	561	27	1275	28	1114	28
I1	709	29	289	12	238	9	183	8
I2	3157	48	88	6	1908	24	1161	18
I5	1177	16	597	5	157	3	456	8
I6	882	15	555	5	59	3	313	7
I9	657	10	158	2	28	2	472	6
I10	1384	12	622	4	389	3	373	5
I11	921	10	283	3	138	2	501	5
I21	254	2	238	1	15	1	0	0
I25	1488	17	331	4	352	4	805	9
I29	1594	17	867	4	156	4	571	9
I30	686	6	332	3	0	0	353	3
I33	3421	17	1204	4	1166	4	1050	9
I37	205	10	0	0	58	4	148	6
I38	1338	21	28	1	1065	12	245	8
I40	420	12	56	4	206	6	158	2
I41	89	7	13	1	35	4	41	2
I42	608	7	0	0	484	5	125	2
I46	598	9	2	1	0	0	536	8
S01	207	16	13	3	87	7	107	6
S02	1075	29	159	9	556	13	361	7
S05	211	13	86	5	75	5	50	3
S09	8841	70	1721	22	4504	33	2617	15
S10	3043	24	5	1	2270	17	767	6
S11	2792	42	139	11	1214	18	1440	13
S12	8248	77	1721	22	3333	31	2881	21
S13	6683	82	1117	27	3093	34	2473	21
S14	8939	64	682	15	5412	32	2845	17
S15	688	8	0	0	202	2	485	6
S16	869	14	0	0	69	4	800	10
S17	434	6	0	0	8	1	426	5
S18	536	8	0	0	0	0	536	8

surface nearly all the time. Mineral layers and layers of less decomposed organic material in some of the soils of this class tend to interfere with water movement: Typic Borofibrists, Terric Borofibrists, Typic Sphagnofibrists, Typic Borohemists, Fibric Borohemists, Terric Borohemists, Typic Borosaprists, Terric Borosaprists, Typic Medisaprists, Terric Medisaprists.

I1. This class consists of deep mineral soils formed in glacial till derived from mixed igneous and metamorphic rocks. If not drained, these soils have groundwater that stands at or near the surface for long periods of time but not throughout the year. Soils in this class differ from classes I2, I37 and I38 in that the pH is less than 5.0 (measured in 0.01 *M* $CaCl_2$) throughout the reaction control section. The particle-size class is coarse-loamy. Drainage is poor or very poor and permeability is moderate or moderately rapid. Some soils in this class have a dense, slowly permeable layer at a depth of 50 cm or more: Aquepts, Aeric Haplaquepts.

I2. This class consists of deep mineral soils formed in glacial till derived from mixed igneous and metamorphic rocks or schist and phyllite. If not drained, these soils have groundwater that stands at or near the surface for a long period of time but not throughout the year. Most of these soils have a layer of dense till at a depth of 1 m or less from the soil surface. The particle-size class is coarse-loamy and the reaction class is nonacid. The soils are somewhat poorly drained to very poorly drained and are moderately permeable above the dense till and slowly permeable in the dense till: Aquepts, Haplaquepts, Aeric Haplaquepts, Typic Fragiaquepts.

I5. This class consists of moderately deep, well-drained, moderately permeable mineral soils formed in glacial till derived from mixed igneous and metamorphic rocks, or from schist and phyllite. These soils have base saturation less than 60% in all subhorizons between depths of 25- and 75-cm below the soil surface. The particle-size class is coarse-loamy or loamy-skeletal. The soils have bedrock between 50- and 100-cm below the soil surface: Typic Dystrochrepts.

I6. This class consists of shallow mineral soils formed in glacial till derived from mixed igneous and metamorphic rocks, or from schist and phyllite. The particle-size class is loamy or loamy-skeletal. The soils are well-drained or somewhat excessively drained and have moderate or moderately rapid permeability. Bedrock is normally tilted or folded and occurs less than 50 cm below the soil surface: Lithic Dystrochrepts.

I9. The soils of this class are deep mineral soils developed in glacial till derived from mixed igneous and metamorphic rocks. These soils have base saturation less than 60% in all subhorizons between depths of 25- and 75-cm below the soil surface. The particle-size class is coarse-loamy or sandy and the soils are well-drained. These soils have a moderately slowly permeable to very slowly permeable layer between 50- to 100-cm below the soil surface: Typic Dystrochrepts.

I10. This class consists of deep mineral soils formed in glacial till derived from mixed igneous and metamorphic rocks. These soils have base saturation less than 60% in all subhorizons between depths of 25- and 75-cm below the soil surface. The particle-size class ranges from coarse-silty to sandy-skeletal. Soils are well-drained or somewhat excessively drained and moderately permeable to rapidly permeable: Typic Dystrochrepts.

I11. This class consists of deep mineral soils formed in glacial till derived from mixed igneous and metamorphic rocks. These soils have base saturation less than 60% in all subhorizons between depths of 25- and 75-cm below the soil surface. Groundwater is present in the soil in the lower layers during winter but disappears in summer. The particle-size class is coarse-loamy. The soils are moderately well-drained and have moderate or moderately rapid permeability: Aquic Dystrochrepts.

I21. This class consists of deep mineral soils formed in glacial till derived from schist and phyllite rocks. These soils have base saturation less than 60% in all subhorizons between 25- and 75-cm below the soil surface. The particle-size class is coarse-loamy or loamy-skeletal. The soils are well-drained or moderately well-drained, and moderately permeable throughout or moderately permeable in the solum overlying slowly permeable substratum: Typic Dystrochrepts, Aquic Dystrochrepts.

I25. This class consists of shallow to very deep mineral soils formed in glacial till or glaciofluvial deposits derived from interbedded sedimentary rocks. Most of these soils are underlain by a fragipan at a depth of 30- to 50-cm below the soil surface. Soil horizons above the pan or bedrock are saturated with water for some months in most years. The particle-size class is loamy, fine-loamy, or coarse-loamy and the soils are very poorly drained to somewhat poorly drained. Permeability is moderate or moderately slow in the solum or above the fragipan and slow or very slow in the fragipan or substratum: Typic Fragiaquepts, Aeric Fragiaquepts, Aeric Haplaquepts, Lithic Haplaquepts.

I29. This class consists of moderately deep mineral soils formed in glacial till derived from interbedded sandstone and siltstone or siltstone and shale. These soils have base saturation less than 60% in all subhorizons at depths between 25- and 75-cm below the soil surface. The particle-size class is coarse-loamy or loamy-skeletal. The soils are well-drained or somewhat excessively drained and moderately permeable throughout. These soils are underlain by bedrock at depths between 50- and 100-cm below the soil surface: Typic Dystrochrepts.

I30. This class consists of shallow mineral soils formed in glacial till derived from interbedded sandstone and siltstone or siltstone and shale. The particle-size class is loamy-skeletal. The soils are moderately well-drained to somewhat excessively drained and are moderately permeable. These soils have bedrock less than 50-cm below the soil surface that is mostly horizontally bedded: Lithic Dystrochrepts.

I33. This class consists of deep mineral soils formed in glacial till derived from sandstone and siltstone. Most soils in this class have a fragipan between 38- and 76-cm below the surface. There is perched groundwater above the pan at some time in most years. The particle-size class is coarse-loamy. The soils are moderately well-drained to well-drained. Permeability is moderately slow to moderately rapid above

the pan and slow or very slow in the pan layers: Typic Fragiochrepts, Aquic Dystrochrepts.

137. This class consists of deep mineral soils formed in glacial till or glaciofluvial deposits derived from mixed igneous and metamorphic rocks. If not artificially drained, these soils have groundwater that stands at or near the surface for long periods of time but not throughout the year. The particle-size class is sandy. The soils are poorly drained or very poorly drained and moderately rapidly permeable or rapidly permeable: Aeric Haplaquepts, Histic Humaquepts, Humaqueptic Psammaquents.

138. This class consists of deep mineral soils formed in marine, lacustrine, glaciofluvial or till material derived from mixed or mixed igneous and metamorphic rocks. Some soils in this class have dense substratum at depths less than 100 cm from the soil surface. These soils have an aquic moisture regime and are somewhat poorly drained to very poorly drained. The particle-size class ranges from fine to loamy-skeletal. Permeability ranges from moderately slow to very slow throughout, or moderately rapid to moderately slow in the solum and slow or very slow in the dense substratum: Aeric Ochraqualfs, Aquic Glossoboralfs, Typic Haplaquepts, Aeric Haplaquepts, Mollic Haplaquepts, Typic Humaquepts, Histic Humaquepts.

140. This class consists of deep mineral soils that formed in coarse-textured glaciofluvial deposits derived from interbedded sandstone and siltstone or mixed igneous and metamorphic rocks. The particle-size class ranges from coarse-loamy to sandy and loamy-skeletal to coarse-loamy over sandy-skeletal. Permeability is moderately rapid to very rapid and soils are well-drained to somewhat excessively drained: Typic Dystrochrepts, Typic Fragiochrepts.

141. This class consists of deep mineral soils formed in sandy glaciofluvial deposits derived from mixed igneous and metamorphic rocks. These soils are saturated with water within 1 m of the soil surface during some part of the year. The particle-size class is sandy. The soils are moderately well-drained and rapidly permeable: Aquic Udipsamments, Aquic Dystrochrepts.

142. This class consists of deep mineral soils formed in loamy glaciofluvial, lacustrine or marine deposits derived from mixed or mixed igneous and metamorphic rocks. These soils are saturated with water within 60 cm of the soil surface at some time of year. The particle-size class ranges from fine to coarse-loamy and coarse-loamy over sandy or sandy-skeletal. Soils are moderately well-drained or somewhat poorly drained and permeability ranges from slow to moderately rapid. Some soils in this class have either carbonates or base saturation that is 60% or more in some subhorizon: Aquic Dystrochrepts, Aquic Dystric Eutrochrepts.

146. This class consists of deep mineral soils formed in glacial till derived from mixed metamorphic and sedimentary rocks. Groundwater stands at or near the surface of these soils at some time during each year but not at all seasons. The particle-size class is coarse-loamy and the soils are very poorly drained or poorly drained. Permeability is moderately slow or moderate in the solum and slow or very slow in the dense substratum: Aeric Haplaquepts, Histic Humaquepts.

S1. This class consists of moderately deep or deep mineral soils formed in glacial till or glaciofluvial deposits derived from mixed igneous and metamorphic rocks. These soils have fluctuating groundwater at or near the soil surface. An ochric epipedon, a surface horizon too thin or with too little organic C to be an umbric horizon, overlies a spodic horizon, a layer in which an amorphous mixture of organic C and Al have accumulated. Particle-size class is sandy. These soils are very poorly drained to somewhat poorly drained and permeability is moderately rapid or rapid: Typic Haplaquods, Entic Haplaquods, Aeric Haplaquods.

S2. This class consists of deep mineral soils formed in glaciofluvial deposits derived from mixed or mixed igneous and metamorphic rocks. These soils have a spodic horizon of amorphous organic C, Fe, and Al accumulation. Particle-size class ranges from coarse-silty to sandy-skeletal. The soils are moderately well-drained to excessively drained and permeability ranges from moderate to very rapid: Typic Haplorthods, Aquic Haplorthods.

S5. This class consists of deep mineral soils formed in glacial till derived from granite or mixed igneous and metamorphic rocks. These soils have fluctuating groundwater at or near the soil surface. They have a spodic subsoil horizon, a layer in which an amorphous mixture of organic C and Al have accumulated. Particle-size class is coarse-loamy. The soils are poorly drained or somewhat poorly drained and moderately permeable: Typic Haplaquods, Aeric Haplaquods, Lithic Haplaquods.

S9. This class consists of deep mineral soils formed in glacial till derived from mixed igneous and metamorphic rocks. These soils have a spodic horizon of Al, Fe, and organic C accumulation in which no one of these elements dominates. The particle-size class is coarse-loamy and the soils are well-drained. These soils are moderately permeable in the upper part, but have dense till or a fragipan within 50 to 100 cm of the soil surface in which the permeability is moderately slow to very slow: Typic Fragiorthods, Typic Haplorthods.

S10. This class consists of deep mineral soils formed in glacial till derived from mixed igneous and metamorphic rocks. These soils have a spodic horizon of Al, Fe, and organic C accumulation in which no one of these elements dominates. The particle-size class is sandy-skeletal. The soils are moderately well-drained or somewhat excessively drained and moderately rapidly permeable: Typic Haplorthods, Aquic Haplorthods.

S11. This class consists of deep mineral soils formed in glacial till derived from mixed igneous and metamorphic rocks. These soils have a spodic horizon of Al, Fe, and organic C accumulation in which no one of these elements dominates. The particle-size class is coarse loamy, loamy skeletal or coarse-loamy over sandy-skeletal. The soils are well-drained and moderately permeable: Typic Haplorthods.

S12. This class consists of moderately deep mineral soils formed in glacial till derived from mixed igneous and metamorphic rocks. These soils have a spodic ho-

rizon of Al, Fe and organic C accumulation in which no one of these elements dominates. The particle-size class is coarse-loamy and the soils are well-drained. Permeability is moderate or moderately rapid. Bedrock occurs within 50 to 100 cm of the soil surface: Typic Haplorthods.

S13. This class consists of shallow mineral soils formed in glacial till derived from mixed igneous and metamorphic rocks. Most of these soils have a spodic horizon of Al, Fe, and organic C accumulation in which no one of these elements dominates. Organic carbon is greater than 6% in humic subgroups. The particle-size class is loamy or thixotropic and the soils are well-drained or somewhat excessively drained. Permeability ranges from moderate to rapid. These soils have bedrock at a depth less than 50 cm from the soil surface: Lithic Haplorthods, Humic Lithic Cryorthods.

S14. This class consists of deep mineral soils formed in glacial till derived from mixed igneous and metamorphic rocks. Aluminum, Fe, and organic C have accumulated in a spodic horizon in which no one of these elements predominates. These soils have groundwater that fluctuates in depth either in or close below the spodic horizon. The particle-size class is coarse-loamy or loamy-skeletal and the soils are somewhat poorly drained or moderately well-drained. Permeability is moderate to moderately rapid. Some soils in this class have either a fragipan or dense substratum within 46 to 100 cm of the soil surface that restricts permeability to slow or very slow: Aquic Fragiorthods, Aquic Haplorthods.

S15. This class consists of deep mineral soils formed in glacial till derived from mixed, mixed metamorphic and sedimentary, or sedimentary rocks. Most of these soils have a spodic horizon of Al, Fe and organic C accumulation in which no one of these elements dominates. Organic carbon is greater than 6% in humic subgroups. Particle-size class is coarse-loamy, thixotropic, or thixotropic over loamy-skeletal. The soils are moderately well-drained or well-drained, and moderately permeable to moderately rapidly permeable. Some soils in this class have either a fragipan or dense substratum within 50 to 100 cm of the soil surface that restricts permeability to slow or very slow: Humic Cryorthods, Typic Fragiorthods, Typic Haplorthods.

S16. This class consists of deep mineral soils formed in glacial till or lacustrine deposits derived from mixed or mixed metamorphic and sedimentary rocks. These soils have a spodic horizon with a moderate amount of organic C. The soils of this class have groundwater that fluctuates in depth either in or close below the spodic horizon. Particle-size class is coarse-loamy, coarse-silty or thixotropic. The soils are somewhat poorly drained or moderately well-drained, and moderately slowly permeable or moderately permeable. Most soils in this class have dense till within 40 to 100 cm of the soil surface that reduces permeability to moderately slow or slow: Typic Cryorthods, Aquic Haplorthods.

S17. This class consists of moderately deep mineral soils formed in glacial till derived from mixed or mixed metamorphic and sedimentary rocks. These soils have a spodic horizon of Al, Fe, and organic C accumulation in which no one of these elements dominates. Particle-size class is coarse-loamy or loamy-skeletal. The soils are well-drained and moderately permeable throughout: Typic Haplorthods.

S18. This class consists of shallow mineral soils formed in glacial till derived from mixed metamorphic and sedimentary rocks. These soils are underlain by bedrock within 50 cm of the soil surface and have a spodic horizon of Al, Fe, and organic C accumulation in which no one of these elements dominates. Particle-size class is loamy or loamy-skeletal. These soils are somewhat excessively drained and moderately permeable: Lithic Haplorthods.

Statistical Analysis of ANC Class vs. Sampling Class

The ANC of lakes is of primary interest to DDRP. Acid neutralizing capacity integrates many watershed processes such as sulfate adsorption, ion exchange, and mineral weathering. Thus, if the sampling classes are meaningful, we would expect there to be a relationship between sampling class occurrence on watersheds and the ANC of the corresponding lakes. As a first step, the percent area of each watershed in each sampling class was used to explore whether the soil class distribution differs among ANC classes. Other more in depth statistical analyses, including regression analysis, are in progress and will be presented in subsequent papers.

One approach was to treat the percent occurrence of each sampling class on each watershed as a quantitative response, and to use a one-way analysis of variance (ANOVA) with the factor levels being the ANC classes. Because each watershed did not have an equal probability of being included in DDRP (Linthurst et al. 1986; Landers et al. 1988) most standard ANOVA packages would not be appropriate. Instead, the regression approach to ANOVA was used. From a computational standpoint, this is identical to weighted least-squares with weights inversely proportional to the probability of inclusion. The regression coefficients are then properly weighted estimates of the mean value of the percent of a particular soil class over watersheds of a given ANC class.

An *F*-test was used to test the hypothesis that the group means are equal. The *F*-test is not entirely appropriate in this case, because most soil classes do not occur on most watersheds. Thus the percentages tend be heteroscadastic (i.e., clumped) at zero, indicating a definitely nonnormal distribution. The mean values also can be misleading, because there tend to be many zeros averaged with a few nonzero numbers. The ANOVA can still provide valuable insight into the relationship between soil class and ANC, and the *F*-tests can still be used as a guide to identifying potentially important relations. The statistical significance level of the test, however, may not be correct. Non-parametric ANOVA procedures such as Kruskal-Wallis also can be biased because the median percentage is zero for most soil classes.

A second approach was to use the chi-square test of homogeneity, which is applicable for distributions clumped at zero. The variable probability nature of

the sample, however, required that the computation of the chi-square statistic proceed in the following nonstandard manner. Let p_i be the probability that the ith watershed in the target population was selected in the sample, and let $w_i = 1/p_i$. An estimate of the number of watersheds in the target population is given by $T_w = \Sigma_i (w_i)$. Let X represent the percent of each watershed covered by some particular soil class, and x represent a particular value of X. Then the cumulative distribution function is given by

$$F(x) = \Sigma_i w_i / T_w$$

where the sum is over all watersheds with $X \leq x$ (i.e., the product $F(x)\ T_w$ estimates the number of watersheds in the target population with $x \leq X$). The distribution function of the percent of each watershed covered by a soil class was calculated for each ANC class. A chi-square test was carried out for each sampling class by dividing the range of percent coverage into intervals, calculating the observed percentage of watersheds in each interval from the cumulative distribution function, multiplying that number by the sample size for the ANC class to obtain an observed frequency (i.e., number of watersheds in that interval), and then calculating the chi-square in the normal manner using these observed frequencies.

Because the distribution of percent occurrence on watersheds is highly variable over soil classes, the same intervals could not be used for all soil classes. The intervals were selected to maximize the number of cells in the chi-square table while keeping the expected frequencies about equal and greater than 5. This approach optimized the power of the test. The high frequency of zero occurrences limited the power of the test, because for many soil classes there were only two-occurrence intervals possible (zero and nonzero percentages).

Results of Statistical Analysis

Examination of the distribution of sampling classes (Table 5) indicates that these distributions are different across alkalinity classes. For example, the very similar Spodosol classes S15, S16, S17, and S18 collectively account for an average of 12% of the watershed area in the highest alkalinity class; they are almost nonexistent (0.03%) in the lowest class. On the other hand, class E3 accounts for 14% of watershed area in the lowest class, but only 3% in the highest class.

The soil classes E3, E5, I2, I6, I9, I25, I38, I46, S9, S10, S12, S14, S16, S17, and S18 have large (i.e., nominal $p < 10\%$) F-values (Table 5). Of these, the mean percentages of classes E3, E5, and S12 decrease as the ANC class number increases, and the mean percentages of classes I25, I46, S16, S17, and S18 increase as

Table 5. Mean percent occurance of soil sampling classes on watersheds within each acid neutralizing capacity (ANC) class.

Soil class	Mean percent ANC class 1	Mean percent ANC class 2	Mean percent ANC class 3	F-value	Significance of F	Significance of Chi square
E2	0.271	0.155	0.362	1.02		
E3	13.910	3.830	2.913	3.54	*	
E5	1.354	1.241	0.417	4.12	*	†
E6	0.004	0.008	0.015	0.40		
H1	2.396	2.915	1.660	1.63		†
H2	0.977	0.793	1.053	0.10		
H3	4.863	3.541	2.755	1.74		
I1	1.339	1.004	0.694	1.04		
I2	0.751	5.049	3.323	4.34	*	**
I5	2.425	0.336	1.877	2.25		
I6	2.715	0.226	1.804	2.42	†	
I9	0.274	0.136	2.400	2.58	†	
I10	4.502	1.532	3.255	0.76		
I11	0.696	0.562	1.815	1.14		
I21	1.448	0.000	0.000	2.55		
I25	1.408	1.568	6.272	3.50	*	
I29	3.624	1.174	3.977	1.58		
I30	0.613	0.087	1.043	1.47		
I33	2.533	4.597	7.451	1.12		
I37	0.141	0.309	0.340	0.77		*
I38	0.105	1.798	0.726	3.16	*	*
I40	1.175	2.628	0.213	1.69		
I41	0.274	0.314	0.094	0.65		
I42	0.000	0.513	0.115	2.13	*	
I46	0.035	0.022	3.087	4.88	**	**
S1	0.230	0.362	0.321	0.14		
S2	3.707	4.052	1.566	0.83		†
S5	0.403	0.820	0.132	1.50		
S9	10.208	13.485	5.806	4.94	**	**
S10	0.069	3.906	1.192	3.99	*	**
S11	3.638	6.048	4.140	0.69		
S12	9.592	7.581	5.198	2.74	†	**
S13	9.334	7.364	5.728	1.67		**
S14	4.009	12.764	8.115	3.97	**	**
S15	0.000	1.173	1.762	0.98		**
S16	0.000	0.679	4.540	5.17	**	**
S17	0.012	0.127	2.926	2.71	†	**
S18	0.019	0.121	2.926	4.71	**	**

*,** Significant at the 0.05 and the 0.01 levels, respectively.
† Indicates significance at 0.1 level.

ANC class number increases. For soil classes I2, I38, S9, S10, and S14, the mean percentage for ANC class 2 is larger than for either class 1 or class 3, and for classes I6 and I9, the mean percentage of ANC class 2 is smaller than for either the ANC class 1 or 3. It is easy to develop hypotheses that imply monotonic relationships between soil class and ANC, and a saturation effect or rate limitation could lead to a threshold or a plateau in the relationship. The possible causes of nonmonotonic relationships are less clear.

The results of the chi-square tests are also summarized by significance level in Table 5. Soil classes E5, H1, I2, I37, I38, I42, I46, S2, S9, S10, S12, S13, S14, S15, S16, S17, and S18 had large (i.e., $p \leq 10\%$) chi-square values. Of these, I42, I46, S15, and S18 had only two classes (zero and nonzero percentages), and had expected frequencies less than 5 in all of the nonzero category cells, so the significance level may be incorrect.

Overall, for 21 of the 38 sampling classes at least one of the statistical tests indicated large differences across ANC classes. These included 10 of 13 Spodosol classes, 8 of 18 Inceptisol classes, 1 of 3 Histosol classes, and 2 of 4 Entisol classes. For 11 classes, both tests indicated large differences. These included 7 Spodosol classes, 3 Inceptisol classes, and 1 Entisol class.

The statistical analysis presented here is somewhat coarse and should not be overinterpreted. Extensive, in-depth analyses currently are being conducted in the context of the three levels of DDRP analyses. Nevertheless, the preliminary analysis presented here does suggest certain patterns. The preponderance of statistical significance of the Spodosol classes suggest that, as a group, these soils are important for ANC, possibly because of the accumulation of oxides and organic material in spodic horizons. Mineralology of parent material also seems to be possibly important. All four Orthod classes formed from metamorphic and sedimentary parent material (S15, S16, S17, S18) have increased occurence with increased ANC, as do the Inceptisol classes formed from similar parent material (I46, I25). In contrast, only one class from igneous and metamorphic parent material (I37) shows an increasing trend. No consistent pattern occurs for the igneous and metamorphic classes. Within the Orthods, these show either decreasing trends or have maximum occurence for the intermediate ANC class.

SUMMARY AND CONCLUSIONS

About 600 soils (mostly phases of soil series) were identified during mapping of 145 forested watersheds in the Northeast. Soil scientists, in cooperation with watershed modelers and statisticians, grouped these soils into 38 sampling classes that are known or expected to have similar chemical or physical characteristics with respect to their response to acidic deposition. This was done in the context of assessing the risk posed by acidic deposition to lakes in the region.

The occurrence of the sampling classes on watersheds of lakes in three classes of acid neutralizing capacity (ANC) was analyzed using ANOVA and the chi-square test of homogeneity. The results indicate that occurrence of sampling class is a significant predictor of ANC class. As a group, Spodosols seem especially important. Mineralogy of parent material may also be important. Other statistical analyses of the relationship between sampling class and surface water chemistry are in progress.

The sampling classes were used as strata for designing the soil sampling scheme for the DDRP. The sampling activities were successfully completed in the Northeast (Lee et al., 1989). The sampling classes are being used for aggregating data for analyses currently underway within DDRP.

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